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PREDICTING PRIMARY FLIGHT GRADES BY AVERAGING OVER LINEAR REGRESSION MODELS: PART 2

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ABSTRACT

Linear regression models are commonly used to predict some criterion variable of interest. Here, the criterion variable of interest is a grade assigned to Navy and Marine Corps student aviators at the end of Primary flight training. It would be of value to be able to predict such a flight grade based on prior existing information. The prior information is inserted into a linear regression model through some number of predictor variables. We are currently focusing our efforts on predictor variables arising from scores on the Aviation Selection Test Battery (ASTB), a final grade from Aviation Pre-Flight Indoctrination (API), and performance on a psychomotor test battery. We then calculated the posterior probability of all possible linear regression models. Some models had an insignificant posterior probability and we may safely ignore them in any averaging over models. The central result of such an exhaustive analysis is the identification of all those models, together with their constituent predictor variables and regression coefficients, that do, in fact, possess a significant posterior probability. The predictions of flight grades for any given values of the predictor variables can then be averaged over these models. A major advantage of this approach is the assessment of the variability of the predictions. Of more immediate concern, these results can be incorporated into the Pilot Prediction System (PPS) at the Naval Aerospace Medical Research Laboratory. The PPS is used to make statistical inferences about the training outcome of a student in flight training given information from a data base. We routinely use the PPS to make predictions about the probability of failure in some post-API phase of training given scores from the ASTB and API. The results from this paper could be inserted into the PPS to make predictions about the flight grade in Primary training.

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INTRODUCTION

Linear regression models are commonly used to predict some criterion variable of interest. Here, the criterion variable of interest is a grade assigned to Navy and Marine Corps student aviators at the end of Primary flight training.

It would be of value to be able to predict such a flight grade based on prior existing information. The prior information is inserted into a linear regression model through some number of predictor variables. We are currently focusing our efforts on predictor variables arising from scores on the Aviation Selection Test Battery (ASTB), a final grade from Aviation Pre-Flight Indoctrination (API), and performance on a psychomotor test battery.

In a previous paper [1], we analyzed the data from 210 subjects who had participated in the Naval Aerospace Medical Research Laboratory's (NAMRL) version of a psychomotor test battery called the CBPT[1]. In that study, we looked at a total of 25 predictor variables. A Bayesian approach was employed to find the posterior probabilities for a selected subset of all possible linear regressions from the set of 25 variables. Subsequently, the posterior probability was used as a weighting function to average the predictions of the flight grade for Primary from each selected regression model. Rather than focusing on just *one* model to the exclusion of all others, the Bayesian model averaging approach averages the predictions of many models to reduce the overall uncertainty of the prediction.

In this paper, we employ the same technique of Bayesian model averaging. However, we pare down the original list of 25 predictor variables to a more manageable number of eight predictor variables. We believe that these eight new predictor variables, because they are averages or composites of the original 25, are a good summary of the information contained in the original 25 predictor variables.

With only eight predictor variables, it is feasible to examine *all* possible linear regressions. There are 256 possible models, ranging from the simplest model with no predictor variables to the most complex model with all eight variables. Note that we are not considering models where predictor variables might enter as interactions with other variables or where the predictor variables are raised to some power.

We then calculate the posterior probability of all 256 linear regression models. Some models have an insignificant posterior probability, and we may safely ignore them in any averaging over models. The central result of such an exhaustive analysis is the identification of all those models, together with their constituent predictor variables and regression coefficients, that do, in fact, possess a significant posterior probability. The predictions of flight grades for any given values of the predictor variables can then be averaged over these models. A major advantage of this approach is the assessment of the variability of the predictions.

The net result is that better predictions can be made for flight students entering Primary flight training. A decision algorithm could be implemented to take advantage of these better predictions. Such a decision algorithm would be an important component in achieving significant cost savings for naval aviation.

Of more immediate concern, these results can be incorporated into NAMRL's Pilot Prediction System (PPS). The PPS is used to make statistical inferences about the training outcome of a student in flight training given information from a data base. We routinely use the PPS to make predictions about the probability of failure in some post-API phase of training given scores from the ASTB and API. The results from this paper could be inserted into the PPS to make predictions about the flight grade in Primary flight training.

ENUMERATION AND LISTING OF ALL POSSIBLE SUBSETS

Before we can begin the analysis, it is necessary to systematically list all possible subsets from the total of eight predictor variables. The grand total of all possible subsets is $2^8 = 256$ subsets. We use the combinatorial formula for choosing k objects from a total of n objects to find the number of subsets with k predictor variables as

[1] CBPT stands for *Computer Based Psychomotor Tests.*

chosen from the universe of n predictor variables. The combinatorial formula is presented below as Equation (1).

$$\binom{n}{k} = \frac{n!}{(n-k)!\,k!} \tag{1}$$

Table 1 lists the results from Equation (1) as k advances from no predictor variables ($k = 0$) in the linear regression model to all the predictor variables ($k = 8$) included in the model.

Table 1: *The enumeration of all possible subsets of predictor variables from a total of 8 as the number of predictor variables is increased from 0 to 8.*

k	$\binom{n}{k}$	$\frac{n!}{(n-k)!\,k!}$
0	$\binom{8}{0}$	1
1	$\binom{8}{1}$	8
2	$\binom{8}{2}$	28
3	$\binom{8}{3}$	56
4	$\binom{8}{4}$	70
5	$\binom{8}{5}$	56
6	$\binom{8}{6}$	28
7	$\binom{8}{7}$	8
8	$\binom{8}{8}$	1
	Sum	256

As an example of the use of Equation (1), see row 5 of Table 1 where we are interested in all possible combinations of $k = 4$ predictor variables from the available total of $n = 8$.

$$\begin{aligned}\binom{8}{4} &= \frac{8!}{4!\,4!} \\ &= \frac{8 \cdot 7 \cdot 6 \cdot 5}{4 \cdot 3 \cdot 2 \cdot 1} \\ &= 70\end{aligned}$$

We must therefore compute 70 linear regression models in order to take into account all possible combinations of four predictor variables from a total of eight predictor variables. Note that the sum in the third column of Table 1 equals 256.

After calculating the number of subsets with k predictor variables, we actually had to explicitly generate these possible combinations. For an example of this task, refer to Table 2, which shows a listing of all possible combinations for $k = 2$ predictor variables. We constructed tables like this for $k = 0$ through $k = 8$. The total number of possible combinations of two predictor variables from a total of eight predictor variables is

$$7 + 6 + 5 + 4 + 3 + 2 + 1 = 28$$

which agrees with row 3 in Table 1.

Table 2: *A listing of the 28 possible combinations of two predictor variables from a total of eight predictor variables.*

1 2	2 3	3 4	4 5	5 6	6 7	7 8
1 3	2 4	3 5	4 6	5 7	6 8	*
1 4	2 5	3 6	4 7	5 8	*	*
1 5	2 6	3 7	4 8	*	*	*
1 6	2 7	3 8	*	*	*	*
1 7	2 8	*	*	*	*	*
1 8	*	*	*	*	*	*
7	6	5	4	3	2	1

THE CRITERION VARIABLE AND THE EIGHT PREDICTOR VARIABLES

In this section, we provide some more details about the criterion variable and the eight predictor variables that are involved in the linear regression models. The criterion variable is the standardized flight grade from Primary flight training. This score was designed to have a mean of 50 and a standard deviation of 10. For our sample of 210 subjects, the mean flight grade was 50.29 and the standard deviation was 10.82.

In subsequent discussions, the eight predictor variables are referred to generically as P1, P2, $\cdots$ P8. They are either the same variables used in the previous referenced analysis or are composites of these variables. P1 is the standardized final grade from API. P2 through P6 are psychomotor variables drawn from the CBPT. P2 is the tracking error when using the stick alone as the controlling device. P3 is the tracking error when the stick, rudder, and throttle are all used as controlling devices. P4 is the average over six sessions of horizontal tracking error. P5 is the average over three sessions of a dual task consisting of horizontal tracking with an absolute difference computation. P6 is the average over four sessions of a spatial orientation skill called the Manikin task.

The correspondence between the notation in this paper and the previous analysis (see Table 1 of Reference [1]) is as follows: P1 is API, P2 is PMT2, P3 is PMT6, P4 is the average of PMT8 through PMT13, P5 is the average of PMT14 through PMT16, and P6 is the average of PMT17 through PMT20. The last two predictor variables, P7 and P8, are composites of four of the subtests that make up the ASTB. These four subtests are the Math/Verbal Test (MVT), the Mechanical Comprehension Test (MCT), the Aviation/Nautical Interest Test (ANI), and the Spatial Apperception Test (SAT). P7 is the same as the AQR composite, which is the following weighted average of the subtests

$$\text{AQR} = (3 \times \text{ MVT }) + (2 \times \text{ MCT }) + (2 \times \text{ ANI }) + (1 \times \text{ SAT }).$$

P8 is the same as the PFAR composite, which is the weighted average of

$$\text{PFAR} = (1 \times \text{ MVT }) + (1 \times \text{ MCT }) + (4 \times \text{ ANI }) + (3 \times \text{ SAT }).$$

The AQR is designed to correlate with academic performance during training, while the PFAR is designed to correlate with pilot flight aptitude.

THE POSTERIOR PROBABILITY FOR ALL 256 MODELS

In reference [1], we presented in detail the Bayesian formalism for model evaluation. The outcome was a formula for computing the posterior probability for any given model. For the kth model, the posterior probability is

$$P(\mathcal{M}_k|D) = \frac{\exp\,(1/2\; BIC_k)}{\sum_{i=1}^{K} \exp\,(1/2\; BIC_i)} \tag{2}$$

where BIC_k stands for the Bayesian Information Criterion (BIC) of the kth model. It is a function of the squared sample multiple correlation coefficient (R^2), the sample size ($n = 210$), and the number of predictor variables ($p = 0$ to 8) included in the linear regression model. Raftery [2] has shown that the BIC is a reasonable approximation to the posterior odds for linear regression models.

In Appendix A, we present the posterior probability for all 256 regression models. This appendix is an EXCEL spreadsheet and contains the necessary components for computing the posterior probability according to Equation (2). All models with posterior probability greater than .01 are highlighted in gray.

Only a few of the 256 models possess any significant posterior probability. The model with by far the largest probability at $P(\mathcal{M}_k|D) = .3633$ is the model consisting of four predictor variables, P1, P2, P7, and P8. This corresponds to the model consisting of the API score, the simple psychomotor tracking variable, AQR and PFAR. The model with the next largest probability is a model with just two predictor variables, P1 and P2. The probability for this model is $P(\mathcal{M}_k|D) = .1821$. This corresponds to the model consisting of the API score and the simple psychomotor tracking variable. Next in line as the third largest model with $P(\mathcal{M}_k|D) = .0595$ is the model consisting of P1, P2, and P7. This corresponds to the model with the API score and the simple psychomotor tracking variable as in the previous two models, together with a third predictor variable, AQR.

BAYESIAN MODEL AVERAGING

There are only 15 models with a probability greater than .01. Appendix B lists these top 15 models together with their associated probabilities. This appendix is divided into two parts; the top half consists of 10 columns and the bottom half consists of 5 columns.

In the top half, the first column contains the model number of the 15 top ranked models. The next nine columns contain the regression coefficients for the constant and the eight predictor variables for the particular model as given in the first column.

The bottom half begins by repeating the listing of the top 15 linear regression models. In the next column is given the prediction of the criterion variable, the standardized Primary flight grade. The third column contains the adjusted posterior probability for each model. This adjustment arises for the following reason. The posterior probability for all 256 models must add up to 1. Check the final row of Appendix A to verify this fact. However, we are selecting only 15 of these 256 models. Together, the posterior probability for these 15 models adds up to .9125, so we must normalize the original posterior probability by dividing by .9125. This adjustment results in the number shown under P(Model).

The next column is the result of multiplying the criterion variable as predicted by the regression model by the adjusted posterior probability. When these values are summed, we obtain the Bayesian model average. The final column is the same exercise for the standard deviations of the predictions. The mean value is subtracted from each prediction and then squared. This value is then multiplied by the adjusted probability and then summed. The square root of this sum then yields the standard deviation.

Data for a numerical example of the prediction that would be made by this technique are presented at the very top of Appendix B. This candidate had an API NSS of 48, a simple tracking score of 25, a complex tracking score of 23, an average horizontal tracking score of 23, an average dual task tracking score of 8, an average Manikin score of 70, a raw AQR score of 158 and a raw PFAR score of 165. The Bayesian Model Averaging prediction for Primary flight grade given these scores is 47.29 with a standard deviation of .98. Employing the usual Normal curve approximation for confidence intervals, we would say that we are 95% confident that this candidate would receive a Primary flight grade within the interval of 45 to 49.

REFERENCES

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2. Raftery, A.E. (1995). In P. V. Marsden (Ed.) *Sociological Methodology 1995,* Bayesian model selection in social research (with Discussion). (pp. 111–163). Cambridge, MA: Blackwell Publishers.

Appendix A

A listing of all 256 linear regression models.

This appendix contains a listing of all 256 linear regression models in an EXCEL spreadsheet format. The first column shows the predictor variables in the model, the second column shows the number of predictor variables, and the third column shows the sample R^2. The next five columns compute the numerator for Equation (2), and the final column presents the posterior probability for each model. The final row gives the denominator of Equation (2) and the sum of the posterior probabilities over all 256 models. This final sum must equal 1.00.

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Appendix A

MODEL	p	R^2	1-R^2	n*ln(1-R^2)	p ln n	BIC	exp(-.5*BIC)	P(Model)
p1	1	0.239	0.761	-57.36	5.35	-52.01	1.97E+11	0.0000
p2	1	0.108	0.892	-24.00	5.35	-18.65	1.12E+04	0.0000
p3	1	0.116	0.884	-25.89	5.35	-20.55	2.89E+04	0.0000
p4	1	0.050	0.950	-10.77	5.35	-5.42	1.51E+01	0.0000
p5	1	0.022	0.978	-4.67	5.35	0.68	7.13E-01	0.0000
p6	1	0.028	0.972	-5.96	5.35	-0.62	1.36E+00	0.0000
p7	1	0.007	0.993	-1.48	5.35	3.87	1.44E-01	0.0000
p8	1	0.036	0.964	-7.70	5.35	-2.35	3.24E+00	0.0000
p1,p2	2	0.320	0.680	-80.99	10.69	-70.29	1.84E+15	0.1821
p1,p3	2	0.303	0.697	-75.80	10.69	-65.11	1.38E+14	0.0136
p1,p4	2	0.267	0.733	-65.23	10.69	-54.53	6.95E+11	0.0001
p1,p5	2	0.242	0.758	-58.19	10.69	-47.49	2.05E+10	0.0000
p1,p6	2	0.245	0.755	-59.02	10.69	-48.32	3.11E+10	0.0000
p1,p7	2	0.250	0.750	-60.41	10.69	-49.72	6.26E+10	0.0000
p1,p8	2	0.245	0.755	-59.02	10.69	-48.32	3.11E+10	0.0000
p2.p3	2	0.134	0.866	-30.21	10.69	-19.52	1.73E+04	0.0000
p2,p4	2	0.116	0.884	-25.89	10.69	-15.20	2.00E+03	0.0000
p2,p5	2	0.111	0.889	-24.71	10.69	-14.01	1.10E+03	0.0000
p2,p6	2	0.115	0.885	-25.66	10.69	-14.96	1.77E+03	0.0000
p2,p7	2	0.114	0.886	-25.42	10.69	-14.72	1.57E+03	0.0000
p2,p8	2	0.135	0.865	-30.46	10.69	-19.76	1.95E+04	0.0000
p3,p4	2	0.119	0.881	-26.61	10.69	-15.91	2.85E+03	0.0000
p3,p5	2	0.116	0.884	-25.89	10.69	-15.20	2.00E+03	0.0000
p3,p6	2	0.118	0.882	-26.37	10.69	-15.67	2.53E+03	0.0000
p3,p7	2	0.121	0.879	-27.08	10.69	-16.39	3.62E+03	0.0000
p3,p8	2	0.143	0.857	-32.41	10.69	-21.71	5.19E+04	0.0000
p4,p5	2	0.054	0.946	-11.66	10.69	-0.96	1.62E+00	0.0000
p4,p6	2	0.063	0.937	-13.67	10.69	-2.97	4.42E+00	0.0000
p4,p7	2	0.053	0.947	-11.44	10.69	-0.74	1.45E+00	0.0000
p4.p8	2	0.078	0.922	-17.05	10.69	-6.36	2.40E+01	0.0000
p5,p6	2	0.036	0.964	-7.70	10.69	2.99	2.24E-01	0.0000
p5,p7	2	0.024	0.976	-5.10	10.69	5.59	6.10E-02	0.0000
p5,p8	2	0.054	0.946	-11.66	10.69	-0.96	1.62E+00	0.0000
p6,p7	2	0.033	0.967	-7.05	10.69	3.65	1.61E-01	0.0000
p6,p8	2	0.062	0.938	-13.44	10.69	-2.75	3.95E+00	0.0000
p7,p8	2	0.039	0.961	-8.35	10.69	2.34	3.10E-01	0.0000
p1,p2,p3	3	0.327	0.673	-83.16	16.04	-67.12	3.76E+14	0.0372
p1,p2,p4	3	0.323	0.677	-81.92	16.04	-65.88	2.02E+14	0.0200
p1,p2,p5	3	0.321	0.679	-81.30	16.04	-65.26	1.48E+14	0.0147
p1,p2,p6	3	0.320	0.680	-80.99	16.04	-64.95	1.27E+14	0.0126
p1,p2,p7	3	0.330	0.670	-84.10	16.04	-68.06	6.01E+14	0.0595
p1,p2,p8	3	0.324	0.676	-82.23	16.04	-66.19	2.38E+14	0.0233
p1,p3,p4	3	0.305	0.695	-76.41	16.04	-60.37	1.28E+13	0.0013
p1,p3,p5	3	0.305	0.695	-76.41	16.04	-60.37	1.28E+13	0.0013
p1,p3,p6	3	0.303	0.697	-75.80	16.04	-59.76	9.49E+12	0.0009
p1,p3,p7	3	0.312	0.688	-78.53	16.04	-62.49	3.71E+13	0.0037
p1,p3,p8	3	0.308	0.692	-77.32	16.04	-61.27	2.02E+13	0.0020
p1,p4,p5	3	0.267	0.733	-65.23	16.04	-49.19	4.79E+10	0.0000
p1,p4,p6	3	0.268	0.732	-65.51	16.04	-49.47	5.53E+10	0.0000
p1,p4,p7	3	0.280	0.720	-68.99	16.04	-52.94	3.14E+11	0.0000
p1,p4,p8	3	0.271	0.729	-66.38	16.04	-50.34	8.52E+10	0.0000
p1,p5,p6	3	0.246	0.754	-59.30	16.04	-43.25	2.47E+09	0.0000
p1,p5,p7	3	0.256	0.744	-62.10	16.04	-46.06	1.00E+10	0.0000
p1,p5,p8	3	0.248	0.752	-59.85	16.04	-43.81	3.26E+09	0.0000
p1,p6,p7	3	0.257	0.743	-62.38	16.04	-46.34	1.16E+10	0.0000
p1,p6,p8	3	0.251	0.749	-60.69	16.04	-44.65	4.97E+09	0.0000
p1,p7,p8	3	0.286	0.714	-70.74	16.04	-54.70	7.56E+11	0.0001

MODEL	p	R^2	1-R^2	n*ln(1-R^2)	p ln n	BIC	exp(-.5*BIC)	P(Model)
p2,p3,p4	3	0.135	0.865	-30.46	16.04	-14.41	1.35E+03	0.0000
p2,p3,p5	3	0.134	0.866	-30.21	16.04	-14.17	1.19E+03	0.0000
p2,p3,p6	3	0.135	0.865	-30.46	16.04	-14.41	1.35E+03	0.0000
p2,p3,p7	3	0.139	0.861	-31.43	16.04	-15.39	2.19E+03	0.0000
p2,p3,p8	3	0.159	0.841	-36.36	16.04	-20.32	2.59E+04	0.0000
p2,p4,p5	3	0.117	0.883	-26.13	16.04	-10.09	1.55E+02	0.0000
p2,p4,p6	3	0.121	0.879	-27.08	16.04	-11.04	2.50E+02	0.0000
p2,p4,p7	3	0.121	0.879	-27.08	16.04	-11.04	2.50E+02	0.0000
p2,p4,p8	3	0.141	0.859	-31.92	16.04	-15.88	2.80E+03	0.0000
p2,p5,p6	3	0.115	0.885	-25.66	16.04	-9.61	1.22E+02	0.0000
p2,p5,p7	3	0.115	0.885	-25.66	16.04	-9.61	1.22E+02	0.0000
p2,p5,p8	3	0.137	0.863	-30.94	16.04	-14.90	1.72E+03	0.0000
p2,p6,p7	3	0.120	0.880	-26.85	16.04	-10.80	2.22E+02	0.0000
p2,p6,p8	3	0.141	0.859	-31.92	16.04	-15.88	2.80E+03	0.0000
p2,p7,p8	3	0.137	0.863	-30.94	16.04	-14.90	1.72E+03	0.0000
p3,p4,p5	3	0.119	0.881	-26.61	16.04	-10.57	1.97E+02	0.0000
p3,p4,p6	3	0.121	0.879	-27.08	16.04	-11.04	2.50E+02	0.0000
p3,p4,p7	3	0.124	0.876	-27.80	16.04	-11.76	3.58E+02	0.0000
p3,p4,p8	3	0.145	0.855	-32.90	16.04	-16.86	4.57E+03	0.0000
p3,p5,p6	3	0.118	0.882	-26.37	16.04	-10.33	1.75E+02	0.0000
p3,p5,p7	3	0.121	0.879	-27.08	16.04	-11.04	2.50E+02	0.0000
p3,p5,p8	3	0.143	0.857	-32.41	16.04	-16.37	3.58E+03	0.0000
p3,p6,p7	3	0.123	0.877	-27.56	16.04	-11.52	3.17E+02	0.0000
p3,p6,p8	3	0.145	0.855	-32.90	16.04	-16.86	4.57E+03	0.0000
p3,p7,p8	3	0.146	0.854	-33.14	16.04	-17.10	5.17E+03	0.0000
p4,p5,p6	3	0.064	0.936	-13.89	16.04	2.15	3.41E-01	0.0000
p4,p5,p7	3	0.057	0.943	-12.32	16.04	3.72	1.56E-01	0.0000
p4,p5,p8	3	0.082	0.918	-17.97	16.04	-1.93	2.62E+00	0.0000
p4,p6,p7	3	0.066	0.934	-14.34	16.04	1.70	4.27E-01	0.0000
p4,p6,p8	3	0.091	0.909	-20.04	16.04	-3.99	7.37E+00	0.0000
p4,p7,p8	3	0.083	0.917	-18.20	16.04	-2.15	2.94E+00	0.0000
p5,p6,p7	3	0.038	0.962	-8.14	16.04	7.91	1.92E-02	0.0000
p5,p6,p8	3	0.067	0.933	-14.56	16.04	1.48	4.78E-01	0.0000
p5,p7,p8	3	0.062	0.938	-13.44	16.04	2.60	2.73E-01	0.0000
p6,p7,p8	3	0.067	0.933	-14.56	16.04	1.48	4.78E-01	0.0000
p1,p2,p3,p4	4	0.328	0.672	-83.47	21.39	-62.09	3.03E+13	0.0030
p1,p2,p3,p5	4	0.329	0.671	-83.79	21.39	-62.40	3.55E+13	0.0035
p1,p2,p3,p6	4	0.327	0.673	-83.16	21.39	-61.77	2.59E+13	0.0026
p1,p2,p3,p7	4	0.336	0.664	-85.99	21.39	-64.60	1.07E+14	0.0106
p1,p2,p3,p8	4	0.331	0.669	-84.41	21.39	-63.03	4.85E+13	0.0048
p1,p2,p4,p5	4	0.325	0.675	-82.54	21.39	-61.15	1.90E+13	0.0019
p1,p2,p4,p6	4	0.323	0.677	-81.92	21.39	-60.53	1.39E+13	0.0014
p1,p2,p4,p7	4	0.334	0.666	-85.36	21.39	-63.97	7.78E+13	0.0077
p1,p2,p4,p8	4	0.326	0.674	-82.85	21.39	-61.46	2.22E+13	0.0022
p1,p2,p5,p6	4	0.321	0.679	-81.30	21.39	-59.91	1.02E+13	0.0010
p1,p2,p5,p7	4	0.330	0.670	-84.10	21.39	-62.71	4.15E+13	0.0041
p1,p2,p5,p8	4	0.325	0.675	-82.54	21.39	-61.15	1.90E+13	0.0019
p1,p2,p6,p7	4	0.330	0.670	-84.10	21.39	-62.71	4.15E+13	0.0041
p1,p2,p6,p8	4	0.324	0.676	-82.23	21.39	-60.84	1.63E+13	0.0016
p1,p2,p7,p8	4	0.358	0.642	-93.07	21.39	-71.68	3.67E+15	0.3633
p1,p3,p4,p5	4	0.308	0.692	-77.32	21.39	-55.93	1.39E+12	0.0001
p1,p3,p4,p6	4	0.305	0.695	-76.41	21.39	-55.02	8.85E+11	0.0001
p1,p3,p4,p7	4	0.315	0.685	-79.45	21.39	-58.06	4.06E+12	0.0004
p1,p3,p4,p8	4	0.309	0.691	-77.62	21.39	-56.23	1.62E+12	0.0002
p1,p3,p5,p6	4	0.305	0.695	-76.41	21.39	-55.02	8.85E+11	0.0001
p1,p3,p5,p7	4	0.313	0.687	-78.84	21.39	-57.45	2.99E+12	0.0003
p1,p3,p5,p8	4	0.310	0.690	-77.92	21.39	-56.53	1.89E+12	0.0002
p1,p3,p6,p7	4	0.312	0.688	-78.53	21.39	-57.14	2.56E+12	0.0003
p1,p3,p6,p8	4	0.308	0.692	-77.32	21.39	-55.93	1.39E+12	0.0001
p1,p3,p7,p8	4	0.342	0.658	-87.90	21.39	-66.51	2.77E+14	0.0274

MODEL	p	R^2	1-R^2	n*ln(1-R^2)	p ln n	BIC	exp(-.5*BIC)	P(Model)
p1,p4,p5,p6	4	0.269	0.731	-65.80	21.39	-44.41	4.41E+09	0.0000
p1,p4,p5,p7	4	0.281	0.719	-69.28	21.39	-47.89	2.51E+10	0.0000
p1,p4,p5,p8	4	0.271	0.729	-66.38	21.39	-44.99	5.88E+09	0.0000
p1,p4,p6,p7	4	0.282	0.718	-69.57	21.39	-48.18	2.90E+10	0.0000
p1,p4,p6,p8	4	0.273	0.727	-66.95	21.39	-45.57	7.84E+09	0.0000
p1,p4,p7,p8	4	0.314	0.686	-79.14	21.39	-57.76	3.48E+12	0.0003
p1,p5,p6,p7	4	0.259	0.741	-62.95	21.39	-41.56	1.06E+09	0.0000
p1,p5,p6,p8	4	0.252	0.748	-60.97	21.39	-39.59	3.94E+08	0.0000
p1,p5,p7,p8	4	0.295	0.705	-73.41	21.39	-52.02	1.98E+11	0.0000
p1,p6,p7,p8	4	0.294	0.706	-73.11	21.39	-51.72	1.70E+11	0.0000
p2,p3,p4,p5	4	0.135	0.865	-30.46	21.39	-9.07	9.31E+01	0.0000
p2,p3,p4,p6	4	0.137	0.863	-30.94	21.39	-9.55	1.19E+02	0.0000
p2,p3,p4,p7	4	0.140	0.860	-31.67	21.39	-10.28	1.71E+02	0.0000
p2,p3,p4,p8	4	0.160	0.840	-36.61	21.39	-15.23	2.02E+03	0.0000
p2,p3,p5,p6	4	0.136	0.864	-30.70	21.39	-9.31	1.05E+02	0.0000
p2,p3,p5,p7	4	0.139	0.861	-31.43	21.39	-10.04	1.51E+02	0.0000
p2,p3,p5,p8	4	0.159	0.841	-36.36	21.39	-14.98	1.79E+03	0.0000
p2,p3,p6,p7	4	0.140	0.860	-31.67	21.39	-10.28	1.71E+02	0.0000
p2,p3,p6,p8	4	0.161	0.839	-36.86	21.39	-15.48	2.29E+03	0.0000
p2,p3,p7,p8	4	0.145	0.855	-32.90	21.39	-11.51	3.16E+02	0.0000
p2,p4,p5,p6	4	0.121	0.879	-27.08	21.39	-5.70	1.72E+01	0.0000
p2,p4,p5,p7	4	0.121	0.879	-27.08	21.39	-5.70	1.72E+01	0.0000
p2,p4,p5,p8	4	0.142	0.858	-32.16	21.39	-10.77	2.18E+02	0.0000
p2,p4,p6,p7	4	0.125	0.875	-28.04	21.39	-6.65	2.78E+01	0.0000
p2,p4,p6,p8	4	0.146	0.854	-33.14	21.39	-11.75	3.57E+02	0.0000
p2,p4,p7,p8	4	0.144	0.856	-32.65	21.39	-11.26	2.79E+02	0.0000
p2,p5,p6,p7	4	0.120	0.880	-26.85	21.39	-5.46	1.53E+01	0.0000
p2,p5,p6,p8	4	0.142	0.858	-32.16	21.39	-10.77	2.18E+02	0.0000
p2,p5,p7,p8	4	0.140	0.860	-31.67	21.39	-10.28	1.71E+02	0.0000
p2,p6,p7,p8	4	0.144	0.856	-32.65	21.39	-11.26	2.79E+02	0.0000
p3,p4,p5,p6	4	0.121	0.879	-27.08	21.39	-5.70	1.72E+01	0.0000
p3,p4,p5,p6	4	0.124	0.876	-27.80	21.39	-6.41	2.47E+01	0.0000
p3,p4,p5,p7	4	0.145	0.855	-32.90	21.39	-11.51	3.16E+02	0.0000
p3,p4,p6,p7	4	0.125	0.875	-28.04	21.39	-6.65	2.78E+01	0.0000
p3,p4,p6,p8	4	0.147	0.853	-33.39	21.39	-12.00	4.04E+02	0.0000
p3,p4,p7,p8	4	0.148	0.852	-33.64	21.39	-12.25	4.56E+02	0.0000
p3,p5,p6,p7	4	0.123	0.877	-27.56	21.39	-6.17	2.19E+01	0.0000
p3,p5,p6,p8	4	0.145	0.855	-32.90	21.39	-11.51	3.16E+02	0.0000
p3,p5,p7,p8	4	0.146	0.854	-33.14	21.39	-11.75	3.57E+02	0.0000
p3,p6,p7,p8	4	0.148	0.852	-33.64	21.39	-12.25	4.56E+02	0.0000
p4,p5,p6,p7	4	0.066	0.934	-14.34	21.39	7.05	2.95E-02	0.0000
p4,p5,p6,p8	4	0.091	0.909	-20.04	21.39	1.35	5.09E-01	0.0000
p4,p5,p7,p8	4	0.089	0.911	-19.57	21.39	1.81	4.04E-01	0.0000
p4,p6,p7,p8	4	0.097	0.903	-21.43	21.39	-0.04	1.02E+00	0.0000
p5,p6,p7,p8	4	0.076	0.924	-16.60	21.39	4.79	9.12E-02	0.0000
p1,p2,p3,p4,p5	5	0.331	0.669	-84.41	26.74	-57.68	3.35E+12	0.0003
p1,p2,p3,p4,p6	5	0.328	0.672	-83.47	26.74	-56.74	2.09E+12	0.0002
p1,p2,p3,p4,p7	5	0.338	0.662	-86.62	26.74	-59.89	1.01E+13	0.0010
p1,p2,p3,p4,p8	5	0.331	0.669	-84.41	26.74	-57.68	3.35E+12	0.0003
p1,p2,p3,p5,p6	5	0.329	0.671	-83.79	26.74	-57.05	2.45E+12	0.0002
p1,p2,p3,p5,p7	5	0.337	0.663	-86.31	26.74	-59.57	8.62E+12	0.0009
p1,p2,p3,p5,p8	5	0.333	0.667	-85.04	26.74	-58.31	4.58E+12	0.0005
p1,p2,p3,p6,p7	5	0.337	0.663	-86.31	26.74	-59.57	8.62E+12	0.0009
p1,p2,p3,p6,p8	5	0.331	0.669	-84.41	26.74	-57.68	3.35E+12	0.0003
p1,p2,p3,p7,p8	5	0.363	0.637	-94.71	26.74	-67.97	5.75E+14	0.0570
p1,p2,p4,p5,p6	5	0.325	0.675	-82.54	26.74	-55.80	1.31E+12	0.0001
p1,p2,p4,p5,p7	5	0.335	0.665	-85.67	26.74	-58.94	6.28E+12	0.0006
p1,p2,p4,p5,p8	5	0.328	0.672	-83.47	26.74	-56.74	2.09E+12	0.0002
p1,p2,p4,p6,p7	5	0.334	0.666	-85.36	26.74	-58.62	5.37E+12	0.0005
p1,p2,p4,p6,p8	5	0.326	0.674	-82.85	26.74	-56.11	1.53E+12	0.0002

MODEL	p	R^2	1-R^2	n*ln(1-R^2)	p ln n	BIC	exp(-.5*BIC)	P(Model)
p1,p2,p4,p7,p8	5	0.361	0.639	-94.05	26.74	-67.31	4.14E+14	0.0410
p1,p2,p5,p6,p7	5	0.331	0.669	-84.41	26.74	-57.68	3.35E+12	0.0003
p1,p2,p5,p6,p8	5	0.325	0.675	-82.54	26.74	-55.80	1.31E+12	0.0001
p1,p2,p5,p7,p8	5	0.358	0.642	-93.07	26.74	-66.33	2.53E+14	0.0251
p1,p2,p6,p7,p8	5	0.358	0.642	-93.07	26.74	-66.33	2.53E+14	0.0251
p1,p3,p4,p5,p6	5	0.308	0.692	-77.32	26.74	-50.58	9.62E+10	0.0000
p1,p3,p4,p5,p7	5	0.316	0.684	-79.76	26.74	-53.02	3.26E+11	0.0000
p1,p3,p4,p5,p8	5	0.312	0.688	-78.53	26.74	-51.80	1.77E+11	0.0000
p1,p3,p4,p6,p7	5	0.315	0.685	-79.45	26.74	-52.72	2.80E+11	0.0000
p1,p3,p4,p6,p8	5	0.309	0.691	-77.62	26.74	-50.88	1.12E+11	0.0000
p1,p3,p4,p7,p8	5	0.344	0.656	-88.53	26.74	-61.80	2.63E+13	0.0026
p1,p3,p5,p6,p7	5	0.313	0.687	-78.84	26.74	-52.10	2.06E+11	0.0000
p1,p3,p5,p6,p8	5	0.310	0.690	-77.92	26.74	-51.19	1.30E+11	0.0000
p1,p3,p5,p7,p8	5	0.342	0.658	-87.90	26.74	-61.16	1.91E+13	0.0019
p1,p3,p6,p7,p8	5	0.342	0.658	-87.90	26.74	-61.16	1.91E+13	0.0019
p1,p4,p5,p6,p7	5	0.282	0.718	-69.57	26.74	-42.83	2.00E+09	0.0000
p1,p4,p5,p6,p8	5	0.273	0.727	-66.95	26.74	-40.22	5.41E+08	0.0000
p1,p4,p5,p7,p8	5	0.315	0.685	-79.45	26.74	-52.72	2.80E+11	0.0000
p1,p4,p6,p7,p8	5	0.316	0.684	-79.76	26.74	-53.02	3.26E+11	0.0000
p1,p5,p6,p7,p8	5	0.298	0.702	-74.30	26.74	-47.57	2.13E+10	0.0000
p2,p3,p4,p5,p6	5	0.137	0.863	-30.94	26.74	-4.21	8.19E+00	0.0000
p2,p3,p4,p5,p7	5	0.140	0.860	-31.67	26.74	-4.94	1.18E+01	0.0000
p2,p3,p4,p5,p8	5	0.160	0.840	-36.61	26.74	-9.88	1.40E+02	0.0000
p2,p3,p4,p6,p7	5	0.141	0.859	-31.92	26.74	-5.18	1.33E+01	0.0000
p2,p3,p4,p6,p8	5	0.162	0.838	-37.11	26.74	-10.38	1.79E+02	0.0000
p2,p3,p4,p7,p8	5	0.162	0.838	-37.11	26.74	-10.38	1.79E+02	0.0000
p2,p3,p5,p6,p7	5	0.141	0.859	-31.92	26.74	-5.18	1.33E+01	0.0000
p2,p3,p5,p6,p8	5	0.161	0.839	-36.86	26.74	-10.13	1.58E+02	0.0000
p2,p3,p5,p7,p8	5	0.162	0.838	-37.11	26.74	-10.38	1.79E+02	0.0000
p2,p3,p6,p7,p8	5	0.164	0.836	-37.62	26.74	-10.88	2.31E+02	0.0000
p2,p4,p5,p6,p7	5	0.125	0.875	-28.04	26.74	-1.31	1.92E+00	0.0000
p2,p4,p5,p6,p8	5	0.146	0.854	-33.14	26.74	-6.41	2.46E+01	0.0000
p2,p4,p5,p7,p8	5	0.145	0.855	-32.90	26.74	-6.16	2.18E+01	0.0000
p2,p4,p6,p7,p8	5	0.149	0.851	-33.88	26.74	-7.15	3.56E+01	0.0000
p2,p5,p6,p7.p8	5	0.145	0.855	-32.90	26.74	-6.16	2.18E+01	0.0000
p3,p4,p5,p6,p7	5	0.126	0.874	-28.28	26.74	-1.55	2.17E+00	0.0000
p3,p4,p5,p6,p8	5	0.147	0.853	-33.39	26.74	-6.65	2.78E+01	0.0000
p3,p4,p5,p7,p8	5	0.148	0.852	-33.64	26.74	-6.90	3.15E+01	0.0000
p3,p4,p6,p7,p8	5	0.150	0.850	-34.13	26.74	-7.39	4.03E+01	0.0000
p3,p5,p6,p7,p8	5	0.148	0.852	-33.64	26.74	-6.90	3.15E+01	0.0000
p4,p5,p6,p7,p8	5	0.099	0.901	-21.89	26.74	4.84	8.88E-02	0.0000
p1,p2,p3,p4,p5,p6	6	0.328	0.672	-83.47	32.08	-51.39	1.44E+11	0.0000
p1,p2,p3,p4,p5,p7	6	0.339	0.661	-86.94	32.08	-54.86	8.17E+11	0.0001
p1,p2,p3,p4,p5,p8	6	0.334	0.666	-85.36	32.08	-53.28	3.70E+11	0.0000
p1,p2,p3,p4,p6,p7	6	0.338	0.662	-86.62	32.08	-54.54	6.97E+11	0.0001
p1,p2,p3,p4,p6,p8	6	0.332	0.668	-84.73	32.08	-52.65	2.70E+11	0.0000
p1,p2,p3,p4,p7,p8	6	0.365	0.635	-95.37	32.08	-63.28	5.52E+13	0.0055
p1,p2,p3,p5,p6,p7	6	0.337	0.663	-86.31	32.08	-54.22	5.95E+11	0.0001
p1,p2,p3,p5,p6,p8	6	0.333	0.667	-85.04	32.08	-52.96	3.16E+11	0.0000
p1,p2,p3,p5,p7,p8	6	0.363	0.637	-94.71	32.08	-62.62	3.97E+13	0.0039
p1,p2,p3,p6,p7,p8	6	0.363	0.637	-94.71	32.08	-62.62	3.97E+13	0.0039
p1,p2,p4,p5,p6,p7	6	0.335	0.665	-85.67	32.08	-53.59	4.34E+11	0.0000
p1,p2,p4,p5,p6,p8	6	0.328	0.672	-83.47	32.08	-51.39	1.44E+11	0.0000
p1,p2,p4,p5,p7,p8	6	0.361	0.639	-94.05	32.08	-61.97	2.86E+13	0.0028
p1,p2,p4,p6,p7,p8	6	0.361	0.639	-94.05	32.08	-61.97	2.86E+13	0.0028
p1,p2,p5,p6,p7,p8	6	0.358	0.642	-93.07	32.08	-60.98	1.75E+13	0.0017
p1,p3,p4,p5,p6,p7	6	0.316	0.684	-79.76	32.08	-47.67	2.25E+10	0.0000
p1,p3,p4,p5,p6,p8	6	0.312	0.688	-78.53	32.08	-46.45	1.22E+10	0.0000
p1,p3,p4,p5,p7,p8	6	0.344	0.656	-88.53	32.08	-56.45	1.81E+12	0.0002
p1,p3,p4,p6,p7,p8	6	0.344	0.656	-88.53	32.08	-56.45	1.81E+12	0.0002

MODEL	p	R^2	1-R^2	n*ln(1-R^2)	p ln n	BIC	exp(-.5*BIC)	P(Model)
p1,p3,p5,p6,p7,p8	6	0.342	0.658	-87.90	32.08	-55.81	1.32E+12	0.0001
p1,p4,p5,p6,p7,p8	6	0.317	0.683	-80.06	32.08	-47.98	2.63E+10	0.0000
p2,p3,p4,p5,p6,p7	6	0.142	0.858	-32.16	32.08	-0.08	1.04E+00	0.0000
p2,p3,p4,p5,p6,p8	6	0.162	0.838	-37.11	32.08	-5.03	1.24E+01	0.0000
p2,p3,p4,p5,p7,p8	6	0.162	0.838	-37.11	32.08	-5.03	1.24E+01	0.0000
p2,p3,p4,p6,p7,p8	6	0.164	0.836	-37.62	32.08	-5.53	1.59E+01	0.0000
p2,p3,p5,p6,p7,p8	6	0.164	0.836	-37.62	32.08	-5.53	1.59E+01	0.0000
p2,p4,p5,p6,p7,p8	6	0.150	0.850	-34.13	32.08	-2.05	2.78E+00	0.0000
p3,p4,p5,p6,p7,p8	6	0.150	0.850	-34.13	32.08	-2.05	2.78E+00	0.0000
p1,p2,p3,p4,p5,p6,p7	7	0.339	0.661	-86.94	37.43	-49.51	5.64E+10	0.0000
p1,p2,p3,p4,p5,p6,p8	7	0.334	0.666	-85.36	37.43	-47.93	2.56E+10	0.0000
p1,p2,p3,p4,p5,p7,p8	7	0.365	0.635	-95.37	37.43	-57.94	3.81E+12	0.0004
p1,p2,p3,p4,p6,p7,p8	7	0.365	0.635	-95.37	37.43	-57.94	3.81E+12	0.0004
p1,p2,p3,p5,p6,p7,p8	7	0.365	0.635	-95.37	37.43	-57.94	3.81E+12	0.0004
p1,p2,p4,p5,p6,p7,p8	7	0.361	0.639	-94.05	37.43	-56.62	1.97E+12	0.0002
p1,p3,p4,p5,p6,p7,p8	7	0.344	0.656	-88.53	37.43	-51.11	1.25E+11	0.0000
p2,p3,p4,p5,p6,p7,p8	7	0.164	0.836	-37.62	37.43	-0.19	1.10E+00	0.0000
p1,p2,p3,p4,p5,p6,p7,p8	8	0.365	0.635	-95.37	42.78	-52.59	2.63E+11	0.0000
		Sum of exp(-.5*BIC) and Probability of Models					1.01E+16	1.0000

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Appendix B

The regression coefficients and constant for the best 15 linear regression models.

This appendix contains the eight regression coefficients and the constant for the best 15 models listed in an EXCEL spreadsheet format. If certain predictor variables do not appear in a given model, then the corresponding regression coefficients are listed as 0.000. The top line contains fictitious data on each of the eight tests. This is used in the numerical example of the prediction of the flight grade by each of the top 15 models. This is shown in the bottom half of the Appendix along with the adjusted posterior probability of each model and the model's contribution to the overall average and standard deviation.

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Appendix B

Model		Constant	P1	P2	P3	P4	P5	P6	P7	P8
	DATA		48	25	23	23	8	70	158	165
1	P1,P2	-41.027	0.781	2.065	0.000	0.000	0.000	0.000	0.000	0.000
2	P1,P3	-55.695	0.742	0.000	2.929	0.000	0.000	0.000	0.000	0.000
3	P1,P2,P3	-55.949	0.756	1.524	1.282	0.000	0.000	0.000	0.000	0.000
4	P1,P2,P4	-46.708	0.773	1.892	0.000	0.435	0.000	0.000	0.000	0.000
5	P1,P2,P5	-41.741	0.789	2.119	0.000	0.000	-0.085	0.000	0.000	0.000
6	P1,P2,P6	-40.941	0.780	2.055	0.000	0.000	0.000	0.003	0.000	0.000
7	P1,P2,P7	-33.026	0.849	2.051	0.000	0.000	0.000	0.000	-0.058	0.000
8	P1,P2,P8	-46.482	0.757	2.041	0.000	0.000	0.000	0.000	0.000	0.034
9	P1,P2,P3,P7	-47.509	0.824	1.535	1.224	0.000	0.000	0.000	-0.056	0.000
10	P1,P2,P7,P8	-41.105	0.858	1.946	0.000	0.000	0.000	0.000	-0.140	0.122
11	P1,P3,P7,P8	-55.120	0.820	0.000	2.736	0.000	0.000	0.000	-0.140	0.126
12	P1,P2,P3,P7,P8	-54.884	0.834	1.454	1.171	0.000	0.000	0.000	-0.138	0.121
13	P1,P2,P4,P7,P8	-47.215	0.853	1.748	0.000	0.497	0.000	0.000	-0.143	0.121
14	P1,P2,P5,P7,P8	-40.472	0.855	1.908	0.000	0.000	0.058	0.000	-0.143	0.124
15	P1,P2,P6,P7,P8	-40.817	0.854	1.913	0.000	0.000	0.000	0.010	-0.141	0.122

Model		Prediction	P(Model)	Average	SD
1	P1,P2	48.09	0.1996	9.60	0.13
2	P1,P3	47.29	0.0149	0.70	0.00
3	P1,P2,P3	47.93	0.0408	1.96	0.02
4	P1,P2,P4	47.70	0.0219	1.04	0.00
5	P1,P2,P5	48.42	0.0161	0.78	0.02
6	P1,P2,P6	48.07	0.0138	0.66	0.01
7	P1,P2,P7	49.81	0.0652	3.25	0.42
8	P1,P2,P8	46.54	0.0255	1.19	0.01
9	P1,P2,P3,P7	49.65	0.0116	0.58	0.06
10	P1,P2,P7,P8	46.74	0.3981	18.61	0.12
11	P1,P3,P7,P8	45.84	0.0300	1.38	0.06
12	P1,P2,P3,P7,P8	46.59	0.0625	2.91	0.03
13	P1,P2,P4,P7,P8	46.23	0.0449	2.08	0.05
14	P1,P2,P5,P7,P8	46.60	0.0275	1.28	0.01
15	P1,P2,P6,P7,P8	46.52	0.0275	1.28	0.02
			0.9999	47.29	0.98

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13. ABSTRACT *(Maximum 200 words)*
Linear regression models are commonly used to predict some criterion variable of interest. Here, the criterion variable of interest is a grade assigned to Navy and Marine Corps student aviators at the end of Primary flight training. It would be of value to be able to predict such a flight grade based on prior existing information. The prior information is inserted into a linear regression model through some number of predictor variables. We are currently focusing our efforts on predictor variables arising from scores on the Aviation Selection Test Battery (ASTB), a final grade from Aviation Pre-Flight Indoctrination (API), and performance on a psychomotor test battery. We then calculated the posterior probability of all possible linear regression models. Some models had an insignificant posterior probability and we may safely ignore them in any averaging over models. The central result of such an exhaustive analysis is the identification of all those models, together with their constituent predictor variables and regression coefficients, that do, in fact, possess a significant posterior probability. The predictions of flight grades for any given values of the predictor variables can then be averaged over these models. A major advantage of this approach is the assessment of the variability of the predictions. Of more immediate concern, these results can be incorporated into the Pilot Prediction System (PPS) at the Naval Aerospace Medical Research Laboratory. The PPS is used to make statistical inferences about the training outcome of a student in flight training given information from a data base. We routinely use the PPS to make predictions about the probability of failure in some post-API phase of training given scores from the ASTB and API. The results from this paper could be inserted into the PPS to make predictions about the flight grade in Primary training.

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